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Inst for Land Rehabilitation

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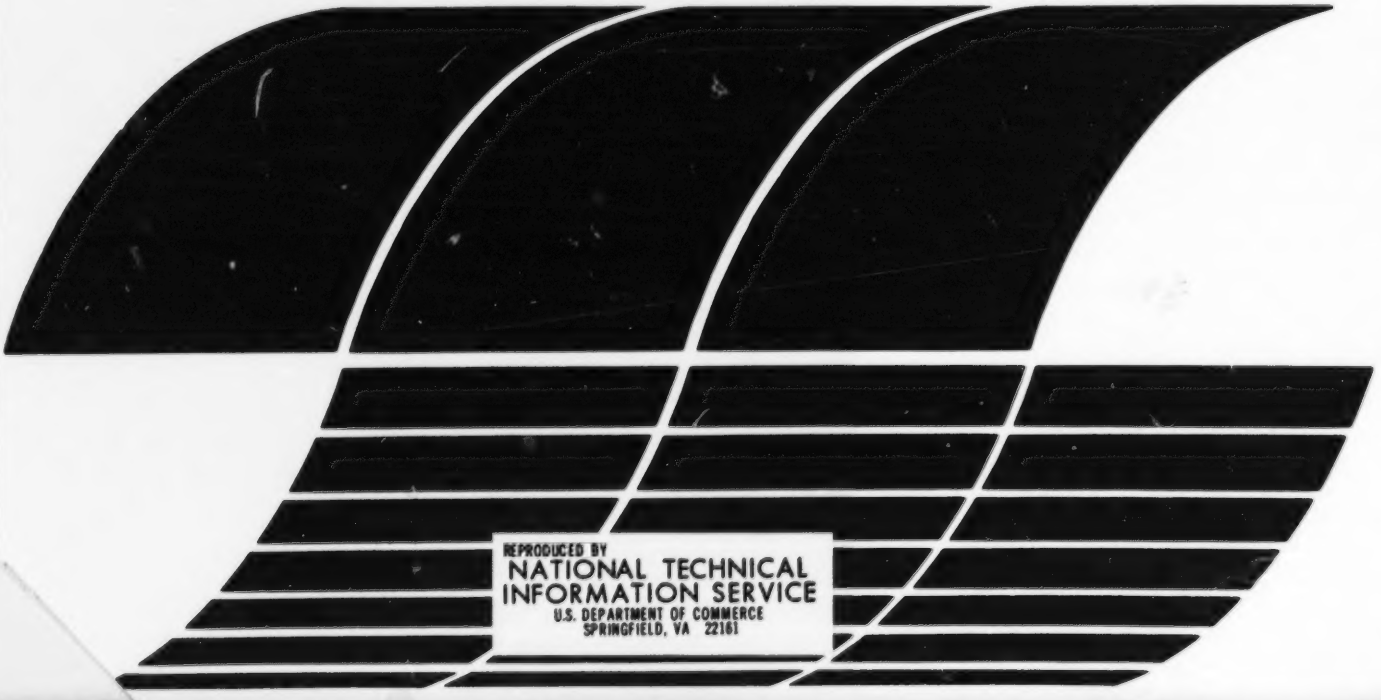
Vegetative Rehabilitation of Arid Land Disturbed in the Development of Oil Shale and Coal

Interagency Energy/Environment R&D Program Report



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Field experiments were established on sites disturbed by exploratory drilling in the oil shale region of northeastern Utah and on disturbed sites on a potential coal mine in south central Utah. Concurrently, greenhouse studies were carried out using soil samples from disturbed sites and processed oil shale. Establishment of container-grown transplants was far more successful than plantings of bare-root seedlings or direct seeding. Early spring planting gave better results than fall planting. Good survival was obtained from summer planting when the soil was moist. Soil surface shaping and application of surface stabilizing materials can be used to collect water runoff and increase plant survival. Propagation of native shrubs from stem cuttings provides a means of multiplying desired biotypes for land rehabilitation. Higher rooting hormone levels are required for some species than are normally used in propagating cultivated species. The most effective container size and shape for growing transplanting materials is one with adequate volume and ribbed sides to prevent root spiraling. Highest seedling vigor is not always associated with the largest seeds because they may have the thickest seed coat. Sizing of seeds, removal of adhering old floral parts, scarification of seed coats and discarding of light seeds improved the germination percentage and survival of seedlings.

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VEGETATIVE REHABILITATION OF ARID LAND DISTURBED IN THE DEVELOPMENT OF OIL SHALE AND COAL

by

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assists in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

Extensive deposits of coal and oil shale exist in the arid and semi arid regions of the Western states that can be developed to meet the Nation's energy requirements. However, many of these fossil fuel deposits occur in environments that have harsh conditions for plant growth. If the benefits to the Nation are to be realized by the development of Western fossil fuels, adequate steps must be taken to maintain environmental quality through vegetation rehabilitation to stabilize the soil surface, reduce runoff pollution, rehabilitate wildlife habitat and restore plant related site aesthetics. The Industrial Environmental Research Laboratory assists in developing new and improved methodologies that will assist in effective rehabilitation of disturbed lands.

The results reported here describe research supported cooperatively by the U. S. Department of Agriculture and the U. S. Environmental Protection Agency at Utah State University Agricultural Experiment Station. These field and greenhouse studies were under the management of the Institute for Land Rehabilitation which had the objective of developing new technologies for establishment of plants under arid conditions on disturbed sites following oil shale and surface coal mining operations.

This report should be of value to those persons responsible for planning and executing revegetation of coal and oil shale disturbed arid and semi arid lands. For further information contact the authors or the Extraction Technology Branch of the Resource Extraction and Handling Division.

David G. Stephan
Director
Industrial Environmental Research Laboratory
Cincinnati

ABSTRACT

Field experiment were established on sites disturbed by exploratory drilling in the oil shale region of northeastern Utah and on disturbed sites on a potential coal mine in south central Utah. These sites are representative of arid locations in the West that could be developed for their energy resources. Concurrently, greenhouse studies were carried out using soil samples and processed oil shale to simulate critical field conditions under which plant germination, establishment, and growth take place.

The objectives of the field studies were to test planting methods, surface stabilizing agents and surface shaping practices and to observe their effects on soil moisture relations under field conditions.

Greenhouse studies were designed to better understand the biology of selected native plants with regard to vegetative propagation, seed germination, seedling competition and growth responses when propagated in various kinds of containers.

Field establishment of container-grown transplants was far more successful than plantings of bare-root seedlings or direct seeding. Early spring planting gave better results than fall planting but good survival was even obtained from summer planting when the soil was moist. Soil surface shaping can be used to collect water runoff and increase plant survival. Further improvement in water harvesting can be obtained by application of surface stabilizing materials. Plant species tolerant to adverse soil conditions such as sandy texture or salinity had a higher survival percentage than other native species.

Propagation of native shrubs from stem cuttings provides a means of multiplying desired biotypes for land rehabilitation. Higher rooting hormone levels are required for some species than are normally used in propagating cultivated species. Also, best rooting response was observed when cuttings of big sagebrush were taken from dormant plants. Stem cuttings from individual plants within a species varied tremendously in rooting ability while others, such as fourwing saltbush responded best from current semi woody summer growth.

The most effective container size and shape for growing transplanting materials is one with adequate volume and ribbed sides to prevent root spiraling. Young transplants originating from seeds survived better in the field than those from rooted cuttings.

Seedling vigor is often critical in field establishment and survival of various saltbush (*Atriplex*) species. Highest vigor is not always associated with the largest seeds because they may have the thickest seed coat. Sizing of seeds, removal of adhering old floral parts, scarification of seed coats

and discarding of light seeds improved the germination percentage and survival of seedlings.

This report was submitted in fulfillment of grant project no. 684-15-10 by Utah State University Agricultural Experiment Station under the sponsorship of the U. S. Environmental Protection Agency. This report covers the period from October 1975 to June 1978. In one experiment, however, field survival of nine shrubs was evaluated in September, 1978.

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Data from three graduate student theses are included in this report which we also wish to acknowledge: Eduardo Alvarez-Cordero (1977), "Stem Propagation of Big Sagebrush (*Artemisia tridentata* Nutt.)"; Kent A. Crofts (1977), "The Importance of Utricle-related Factors in Germination and Seedling Vigor of Four Species of Perennial Atriplex": and Jerry R. Barker (1978), "The Influence of Containers and Propagation Methods on Shrub Growth Before and After Field Planting".

Finally, we acknowledge the continuing interest expressed in the project by Elmer Clark, Associate Director, Utah Agricultural Experiment Station and to Eilif V. Miller who coordinated the study for the Science and Education Administration USDA.

[1] White River Shale project is a joint venture sponsored by Sun Energy Development Co., Phillips Petroleum Co., and Sohio Petroleum Co.

SECTION 1

INTRODUCTION

Revegetation is one of the major mitigation practices required to ameliorate environmental surface impacts that could be caused by development of an oil shale extractive and retorting industry in Utah and Colorado and by surface mining and its associated land manipulations in the western states. Serious disturbance may be imposed on the land by test drilling, exploration, and surface grading as well as by surface mining and disposition of processed materials or spoil.

There has been an increasing emphasis on the use of native plants for vegetative rehabilitation of disturbed lands. Many state regulations specify either that native plants be used exclusively or wherever possible. Such emphasis assumes that there is sufficient information about the ecological tolerances and responses of native species to use them in rehabilitation programs under extreme site conditions and further, that propagation and planting methodologies are known.

Until recently, revegetation of disturbed areas and mine spoil disposal sites in the arid west has not been required. Thus, a technology for rehabilitation was not developed for these difficult problem areas.

Some information is available from the field of range management and improvement (Valentine 1971). However, many workers advise avoiding difficult sites and areas of low rainfall. The conclusion of Bleak et al, (1965) in attempting to direct-seed exotic grasses in a region of drought and soil salinity was to use native plants, possibly shrubs, and to seek better ways to assure establishment. The work of Plummer et al. (1968) is especially helpful in describing some potentially useful native species for land rehabilitation. Species tried in oil shale revegetation studies by Baker and Duffield (1973) gave varied responses as might be expected by their origins as either native plants or cultivated species used in rehabilitation.

It may be possible to grow plants on disturbed arid sites if sufficient attention is exercised in replacing topsoil, leaching, seedbed preparation, fertilization, mulching, and irrigation (Block and Kilburn, 1973). However, costs and the non-availability of water may preclude such practices in some arid locations. Further, any long term commitment to supply scarce or expensive inputs to a rehabilitation program may reduce its feasibility.

Thus, a viable approach is to use adapted native or naturalized plant species that require minimal inputs and can survive under harsh site conditions. To follow such an approach, considerable information must be developed about

the biology and utilization of native species (McKell et al. 1972) and improve on existing methods for propagation and establishment (Plummer et al. 1968, Cook et al. 1974).

The present work attempts to fill in some of the more serious information gaps in previous work so that new approaches can be made to rehabilitate disturbed arid lands. The major research objectives of these studies were to develop basic information and methods for establishing native plants under harsh environmental conditions. Specifically, we set out to: 1) develop propagation and transplanting techniques for selected native species in a number of harsh sites of varying soil properties. 2) investigate the suitability of selected materials for soil surface stability that would also promote water harvesting, 3) study the ecology of selected native species in relation to germination, seedling vigor, and field survival, and 4) study soil moisture patterns in relation to plant survival. Two or more studies were conducted under each of these objectives.

SECTION 2

CONCLUSIONS

From the nine studies reported here a number of conclusions can be drawn. Each of these conclusions takes on a greater significance for arid land rehabilitation when considered with other conclusions developed in this project. Experience gained in pursuing these studies has strengthened our belief that plant establishment is possible under the often difficult environments and soils of arid sites if extra concern is given to using adapted species, employing proper planting practices in the appropriate time of the year and understanding some of the ecological limits and characteristics of various native shrubs and grasses.

Major conclusions reached in this series of studies are as follows:

1. Vegetative propagation of big sagebrush, an important native shrub, is more successful when cuttings are taken during dormancy or shortly after. Rooting hormone treatment at relatively high levels, 2.0 percent indolebutyric acid in talc powder, is required to stimulate root initiation in big sagebrush.

2. The most favorable container size to use in propagating shrub seedlings or rooted cuttings appears to be one which provides an adequate rooting volume. Small cylindric containers restrict root and top root biomass. Plants propagated from seedlings have a slightly higher field survival rate than those from rooted cuttings.

3. Shrubs, native to arid regions vary in their tolerance to stress conditions characteristics of disturbed sites. Careful species selection according to ecological conditions of a given site can result in increased survival. Container-grown planting stock gives better survival than bare-root planting stock. Direct seeding may fail on dry sites or in dry years. Spring transplanting results in better survival than fall transplanting. Even mid summer plantings may be undertaken if healthy container grown plants are used and the soil is moist or limited supplemental irrigation is provided.

4. Soil surface stabilizing agents may reduce soil surface looseness and promote runoff for possible use in plant establishment. Duration of effectiveness may be limited depending on environmental conditions but in this study it did no extend over 1 year.

5. Creating small basins may be a method for harvesting water. Treatment of the side slopes with soil surface stabilizing materials may increase runoff and decrease growth of competiting weedy annual plants the first year after establishment.

6. Seedling vigor of *Atriplex*, an important genus for arid land rehabilitation is the result of many factors, among which are utricle size and utricle wall thickness. Careful collection of only ripe utricles accompanied by cleaning to remove unfilled utricles prior to sizing can increase germination percentage. Separate scarification of individual size classes can also improve germination and reduce the number of broken utricles. Thickest utricle walls are associated with largest utricles. Medium to small well-filled utricles may give the highest germination percentages and greatest seedling vigor.

7. Survival of seedling transplants is closely related to size, age, and effectiveness of the root system produced prior to planting. A container allowing adequate root growth without spiraling is superior to containers which restrict early growth.

8. Soil moisture depletion patterns can give good evidence of root activity. Plants which are slow to withdraw moisture are possibly those with a less adequate root system. Surface treatments to eliminate or reduce a weedy plant cover may enhance the soil moisture supply for subsequent plant establishment.

9. Soil properties are important as a guide to selection of plant species tolerant to extreme soil characteristics. Taken together, these conclusions can be helpful in developing a program for plant propagation and establishment and growth in arid disturbed sites.

SECTION 3

RECOMMENDATIONS

Forming recommendations from single studies or those that have been conducted for only one or two years is especially hazardous when dealing with establishment of native plant species on harsh arid sites with complex heterogeneous soil materials and variable climatic conditions. However, when results and observations from longer studies conducted under similar environmental conditions along with biotypes of the same or related species are considered in relation to results from these studies, recommendations tend to take on more reliability. It is under this context that these recommendations are given. The areas where they are applicable are the oil shale region of Utah, Wyoming and Colorado or the Four Corners of Utah, Arizona, New Mexico and Colorado.

1. Vegetative propagation by stem cuttings may substitute for seed propagation where seeds are unavailable or hard to germinate or where large numbers of a specific genotype are desired. Big sagebrush may be vegetatively propagated, provided certain criteria are used. Stem cuttings of current growth should be taken with the growing tip remaining on the cutting. The best time to collect is when plants are in a dormant physiological condition or soon after. The cuttings need to be obtained from individual plants that have the ability to root from cuttings. This information can be obtained only from previous studies dealing with individual plants, as rooting ability varies extensively among individual plants. A rooting hormone treatment of about 2.0 percent indolebutyric acid is required. Care must be utilized while the cuttings are in the propagation chamber that the temperature does not exceed 29^{o}D (85^{o}F) and that leaves and terminal buds are not kept excessively moist. Rooted cutting should be planted in propagation containers when roots begin to branch. We have used mainly Jiffy peat pellets sizes 7 and 9 in our studies.

2. An appropriate container size and shape should be selected for native shrubs. In general, the larger the container the higher the percent plant survival, providing the plants are of high quality and the roots have utilized the total rooting volume. An over abundance of soil not enmeshed by roots may be detrimental as it might break away during field handling and planting causing root breakage and poor plant survival. Plants should have good top growth and root biomass that utilizes the entire soil medium. Container-grown plants to be used for early spring field planting can generally be of a smaller volume than those used for summer or fall planting. However, plants must be virorous and hardened to field conditions. Plants propagated from seedlings generally seem to have a higher survival rate than those from rooted cuttings, but this could be a factor of age and quality.

3. Plants to be used in planting disturbed arid sites should be indigenous or tested for adaptation to the specific soils and climatic conditions of the area to be vegetated. A knowledge of the various soil materials with their characteristics and selection of plants resistant to the salinity and other stress conditions of each soil type are essential for successful plant survival.

Plant species or ecotypes being used for revegetation must have the potential to reproduce naturally on those soil materials in which they are being established or they will be of limited value.

4. Choice of planting methods is critical for plant establishment on arid sites. In general, direct seeding is not recommended due to the high incidence of failure where precipitation is so variable and assurance of success in revegetation is necessary. Transplanting of container-grown stock will give higher survival success than planted bare-root stock. Successful establishment can be obtained by early spring planting in moist soil, with planting stock in a dormant condition. For best results with bare-root stock planting should be done only in early spring using dormant material. Later plantings should use only container-grown stock. Density of planting should be determined from predevelopment or baseline studies and from needs related to intended post development uses. Planting bare-root stock at a higher than necessary planting rate to compensate for plant losses may be more economical than using normal numbers of container-grown plants. A limited amount of water may be necessary when transplanting containergrown stock in summer or fall. Plantings in dry soil are not recommended.

5. Plants of the genus *Atriplex* are extremely variable in growth habit and size and contain some of the more important species for planting in harsh, saline, arid sites. Utricle (seed) size with its variations in wall thickness has a definite effect on seed germination. We have observed that the larger utricles generally enclose larger seeds but have thicker utricle walls. Small to medium size utricles have the greatest seed fill and germinate quicker. A seed fill of fifty percent or above is commercially acceptable for fourwing saltbush and thirty-five to forth percent for shadscale. There may be twice as many small utricles as large ones for each kilogram of seed which would have the capability of producing twice the number of seedlings.

6. It is possible to establish plants in the diversity of soil types that were studied provided certain guidelines or criteria are followed. In some instances such as silty clay loam from the Mancos shale formation on Wildcat Mesa or a crushed gray shale outcrop it would be best to mix these with other soil materials to change some soil characteristics such as texture and salinity. The soil must contain an accumulation of soil moisture and plant species must be selected and planted in accordance with the various soil materials. Higher plant survival is assured by planting early in the spring using quality plant stock. Plantings made later than early spring should always be from container-grown quality stock and given one or two liters of water.

7. Management practices that results in the accumulation and retention of soil moisture will generally have a beneficial effect on plant establishment and survival. Moisture is a major limiting factor in plant survival on arid sites. Crushing and compaction of disturbed soil-spoils may increase water holding capacity and reduce percolation. In some cases, mixing of soil materials may be necessary, to achieve desirable soil characteristics. One season of fallow for moisture accumulation in the area to be planted is often a beneficial practice. Elimination of weedy plant competition for the first couple of years to conserve soil moisture will increase survival of desired plants.

Other practices for increasing the supply of available moisture that are recommended include water harvesting and soil surface grading. Soil surface stabilizing materials such as polyvinyl acetate should be applied at rates appropriate to local soil and weather conditions to promote optimum surface runoff to planted areas. Creation of basins 75 cm in diameter or larger can be useful for obtaining runoff to plants in the bottom of the basin. Treatment of the basin slopes will improve water harvesting as well as create a temporary reduction in weed competition. To obtain optimum water harvesting basin slope should be continuous to the plant in the bottom of the basin and not flattened out into a saucer condition.

SECTION 4

PROCEDURES

FIELD STUDY SITES

Two field research sites were used in conducting the studies. One was in the oil shale region of northeastern Utah. The other was in the Henry Mountains coal field of south central Utah, an area typical of the Four Corners region of the United States.

Oil shale study site--The main study area was at 1560 m elevation on 7 ha of gently sloping hillside in the big sagebrush (*Artemisia tridentata*)-shadscale (*Atriplex confertifolia*) vegetation type (Figure 1). The climate of the area is semi-arid with annual precipitation averaging 18 to 23 cm. Dry hot summers and cold winters are characteristic of the site with the frost-free period averaging 110 days. The soil, formed from sandy alluvium, is classified as a sandy loam and has a depth greater than 150 cm. The rooting zone is moderately calcareous and alkaline (pH 8.0 to 8.3). Other study sites were located on exploration areas scattered over the two 2000-ha oil shale prototype lease areas designated Ua and Ub by the Department of Interior (Federal Register 1973).

FIGURE 1. OIL SHALE SITE

Henry Mountains study site--Six field study sites of 150 m^2 each were fenced in the fall of 1976. Three were on predominant soils of the area and three were on outcrops of major geologic overburden strata. Elevation of the study sites ranged between 1680 and 1830 m and were located in a vegetation type dominated by *Atriplex canescens*, *xanthocephalum sarothrae*, *Oryzopsis hymenoides* and *Hilaria jamesii* (Figure 2). Average annual precipitation is 21 cm which occurs throughout the year with a slightly higher amount in late summer. The frost-free period is about 151 days. Three sites were on disturbed topsoil of sandy loam, loamy sand, and silty clay. The other three sites were on degraded escarpment outcrop layers representing potential overburden materials from sandstone, siltstone, and mixed clay-sandstone geologic strata over the coal seam.

FIGURE 2. TYPICAL HENRY MOUNTAIN SITE. THE COAL SEAMS ARE BENEATH THIS SURFACE.

STUDY METHODS

Ten related studies were undertaken to meet the four main objectives set for the project. Procedures are described separately under the title of each study.

Develop Propagation and Plant Techniques

Stem Cutting Propagation of Big Sagebrush--

Big sagebrush is one of the most common shrubs of the Intermountain western states. Previous efforts to vegetatively propagate this species for use in growing plants for rehabilitation plantings have been variable or unsuccessful. Some of the procedures used in the final study were developed in preliminary tests. Three problems were identified as being critical: 1) the appropriate phenological stage for collection of cuttings, 2) the appropriate level of root-stimulating hormone and 3) variability among individual plants in ability to root from stem cuttings.

Twenty mature sagebrush (*Artemisia tridentata*) plants of uniform size were selected and permanently marked near the oil shale field research site. Ninety stem tip cuttings from 8 to 12 cm in length were clipped from each of 5 source plants per sampling date. Sampling dates were at 2 week intervals from bud break: March 26, April 10, April 24, and May 8. Cuttings were kept moist and returned to the greenhouse where five replications of 30 cuttings each were given a root hormone treatment (0.3 or 2.0% Indolebutyric Acid in a talc base) at each sampling date.

Cuttings were placed in sterile peat pellets and maintained in a moist root chamber for 40 days. Percent rooting was calculated as well as rooting vigor.

Container Volume as a Factor in Propagating Shrub Seedlings--

One of the unanswered questions in propagating native shrub seedlings for transplanting to disturbed arid sites is what special requirements exist, if any, to accommodate the different rooting habits but at the same time avoid unnecessarily large container volumes. After a review of literature and discussions with native plant propagation specialists four container types differing in size and shape were selected for study (Barker 1978): 1-quart milk carton (1176 cm^3 volume), a handmade deep carton 5 cm in diameter and 42.5 cm deep (668 cm^3 volume), a five-unit "tubepak" with ribbed side walls and individual units of 3.7 x 5.0 x 17.5 cm (315 cm^3)m and "R. L. Single Cell" cylindrical containers with a diameter of 2.5 cm and a depth of 16 cm (120 cm^3) (Figure 3). Three shrub species 1/ with different root growth habits were grown in the containers: fourwing saltbush (*Atriplex canescens*) with a branched moderately deep root system, greasewood (*Sarcobatus vermiculatus*) with a deep root system, and spreading rabbitbrush (*Chrysothamnus linifolius*) with a spreading root system.

Cuttings and seeds were obtained from the general area of the field study site. Seeds were collected in late fall and cuttings in mid-winter. Seedlings and rooted cuttings were planted in the various containers and grown under controlled greenhouse conditions for 20 weeks.

Three plants per treatment (4 container types, 3 species, 2 propagation methods - seeds and cuttings) were harvested at 4-week intervals for 20 weeks

1/ For convenience in referring to scientific plant names, the following symbols are employed in tables: *A. canescens* (ATCA) *S. vermiculatus* (SAVE) and *S. linifolius* (CHLI).

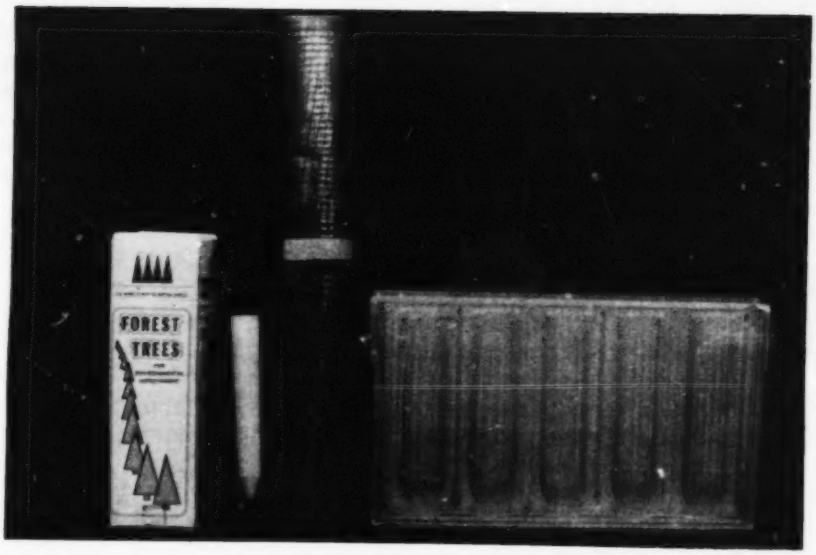

FIGURE 3. CONTAINER TYPES.

to observe shoot length, shoot biomass, and root biomass. Thus, a total of 360 plants were grown in the study.

An additional set of seedlings and rooted cuttings of each species were grown in the four container types for 20 weeks and then transplanted to glass-fronted soil filled root growth observations chambers (Figure 4). Root growth was observed one month after transplanting to determine the carry over effects if any, on root growth patterns.

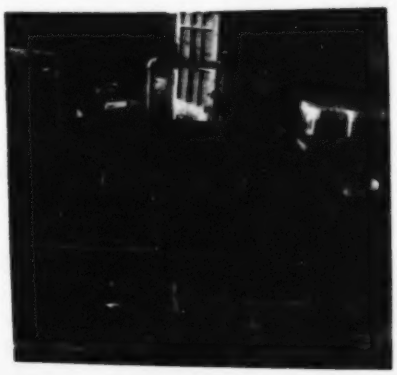

FIGURE 4. ROOT GROWTH OBSERVATIONS CHAMBERS.

Planting Techniques, Season and Type of Planting Stock--

A common question facing the rehabilitation technician is whether to attempt revegetation under arid conditions by direct seeding or transplanting. Also, of concern is whether to plant in the fall when there is a chance of future moisture even though cold temperatures and frost heaving are possible or to wait until spring when temperatures are favorable but the chances of future precipitation are diminished. Two studies were carried out to answer these questions plus evaluate performance of several native species.

A study involving spring and fall planting of seeds, bare root transplants and container-grown plants in soil was established in the oil shale region on three disturbed sites. Four replications of nine shrub species were planted/seeded at each location in late October, 1975 and in April, 1976. Plant species tested were cuneate saltbush (*Atriplex cuneata*), winterfat (*Ceratoides lanata*), Green's rabbitbrush (*Chrysothamnus greenii*), black sagebrush (*Artemisia nova*), big sagebrush (*Artemisia tridentata*), spreading rabbitbrush, greasewood, fourwing saltbush, (*Atriplex canencens*) and shadscale (*Atriplex confertifolia*). Three planting treatments were also followed: (a) regular placement of transplant in a shovel-hole and firming soil around transplant (control), (b) planting in a shovel-hole plus 1 liter of water and (c) planting plus 1 liter of water and a 12 gm slow release pellet of 14-4-6 fertilizer in each planting hole. Direct seeding was accomplished by furrow planting with depth of seed covering dependent on seed size and species.

Data recorded for this study were survival, growth, and observations of competition and animal utilization.

A second study was established at the Henry Mountains coal field in April, 1976 to test survival of container grown plants in a spring planting. The season was one of the driest in recent history in the area and so tested the possibility for transplant survival under unusually arid conditions. Fourwing saltbush, cuneate saltbush, shadscale, Russian wildrye (*Elymus juncens*) and Indian ricegrass (*Oryzopsis hymenoides*) were propagated in the greenhouse and 24 plants of each species were transplanted in six locations. At planting time each transplant received 2 liters of water. Twelve of the plants also received a liquid fertilizer of 20-20-20 (NPK each at 112 Kg/ha) in the irrigation water. All plots were fenced with a 1-inch mesh wire netting. To offset the lack of summer rainfall plants received 1 liter of water each two weeks during July and August.

Percent survival and wildlife damage were recorded in late fall after one growing season.

Evaluate Soil Surface Stabilizing Materials for Use in Water Harvesting

Field Evaluation of Materials Under Arid Conditions--

Loose particles of soil or disposal materials are an environmentally undesirable result of disturbance of disposal. Surface stilization would bring two major benefits. First, there would be less damage to seedlings from the abrasive actions of wind-driven particles. Second, because small particles enhance fertility and soil moisture holding capacity, holding

them in place would improve changes for plant establishment and growth. An additional hoped-for benefit would be that surface stabilizers would aid in water harvesting when applied to moderate slopes. The purpose of this study was to test six surface stabilizing materials for adaptation to local conditions.

Four replications of six materials at 3 rates plus two check plots were applied to 1.4 meter square plots on July 1. Table 1 describes the materials and rates used. Rates used were the manufacturers recommended rate, 1/2 that rate and double that rate. Two replications were on a 1:5 north facing slope and two were on a 1:10 east-facing slope. One replication on each slope was top-dressed with a 2.5 cm layer of processed oil shale that had passed through a 8 mm mesh screen.

A 7.5 cm deep furrow was formed at the base of each plot to catch runoff. Later a container-grown 4-wing saltbush plant was planted in the bottom of each furrow.

Surface strength and binding properties were rated on a 1-5 scale after 2 weeks and after 7 weeks as well as in the following spring. A runoff evaluation was obtained by observing the portion of one liter of water applied to the upper margin of the plot that arrived to the bottom furrow. Runoff observations after a summer thundershower were also recorded. Plant survival was rated 1 year after planting.

Water Harvesting Basins Treated with Soil Surface Stabilizers--

Many plants become established in small depressions where temperature and soil moisture are more favorable than in exposed sites. This study was carried out to measure the amount of runoff, if any, that could be collected from surface stabilizer - treated slopes of artificial basins and whether subsequent plant survival would be increased by surface treatments to shallow basin slopes.

Twenty small basins, 75 cm in diameter by 10 cm deep and 20 larger basins 150 cm in diameter by 20 cm deep were prepared in the field study site. A 3.8 liter (gallon) can was installed in the bottom of each basin flush with the soil surface. A 20 cm square patch of 6 mil sheet plastic with a small hole in the middle was laid over the top of the can to prevent water running down the side of the can. A light cover of soil was placed over the plastic prior to application of the soil stabilizer, a formulation of polyvinyl acetate.

To the 20 small basins, four replications of the concentrate of Union Oil Co. produce 3011 were applied on July 14, 1976 with a pressure hand sprayer at the following rates: Check, 1900 l/ha (200 gal/ac) of concentrate, 3800 l/ha concentrate, 950 l/ha concentrate + 940 l/ha reapplied, and 1900 l/ha concentrate + 1900 l/ha reapplied. To the 20 large basins four replications of the following rates of the concentrate Aerospray 70 were applied: check, 475 l/ha (50 gal/ha) 950 l/ha, 237 l/ha + 237 l reapplied and 475 l/ha + 475 reapplied. All concentrates were applied in a 1:6 dillution in water using a hand pump pressure sprayer. All treatments cured rapidly with no difficulties observed.

TABLE 1. SOIL SURFACE STABILIZING MATERIALS TESTED IN UTAH OIL SHALE REVEGETATION STUDY SITE

Name	Nature of Material, Source	Rates Used	Concentration in H_2O
Check			-
Plastic	Clear Plastic	1 layer - 9 mil.	-
Coherex	Asphalt emulsion Big Bear Oil Co.	600 1200 2400 gal/acre (liquid emulsion)	1:5
Soil seal	Copolymer of Methacrylates and Acrilites Soil Seal Corp.	1090 2180 4360 gal/acre (liquid emulsion)	1:10
Aerospray - 70	Polyvinyl acetate American Cyanimid	25 50 100 gal/acre (liquid emulsion)	1:10
Trastan	Ammonium lignosulfonate Arthur Trask Co.	1000 2000 4000 lbs/acre (water soluble powder)	1:10
Paracol 1461	Lignosulfonate + resins and wax Hercules Inc.	250 500 1000 gals/acre (liquid emulsion)	1:5
TerraTack II	Powdered extract of seaweed Grass Growers, Inc.	45 90 180 lbs/acre (water miscible powder)	1:10

* The medium rate was generally the rate recommended by the manufacturer, U. S. Bureau of Mines Stabilization Consultant.

Harvest of water from a rainfall event of .17 inches which occurred 2.5 months after the basins were established, was measured on September 23. Water collected in the cans was withdrawn with a small suction pump. Subsequently a simulated rain of .15 cm was applied to the basins and measured.

In April of the following year cans were removed and container-grown fourwing saltbush plants were planted in the basins. An additional set of control plants were planted on the flat areas between the basins.

Ecology of Selected Native Plants

Germination and Seedling Vigor of Four Atriplex Species--

Obtaining vigorous seedling growth is a very important factor in successful plant establishment under arid and generally saline conditions. Reports in the literature (McKell 1972) that seedlings from larger seeds produce more vigorous seedlings give reason to search for ways to identify and collect or produce larger seeds of species than would be used for rehabilitation plantings. Seed fill of *Atriplex* was reported to be low many years previously (Collins 1901) but ways to deal with this problem are still needed. Eratic results have characterized much of previous work with *Atriplex* seeds. To identify some of the reasons for variability in germination and low seedling vigor in four saltbush species, time to seed maturity, seed size, seed fill, wall thickness, and germination responses were studied.

To determine if any differences in utricle [1/] fill or size occurs over time and in relation to position on the stem, utricles of fourwing saltbush (*Atriplex canescens*), shadscale (*A. confertifolia*), Gardner saltbush (*A. gardneri*) and cuneate saltbush (*A. cuneata*) were collected from three stem locations of marked plants as soon as they were mature in late summer starting with cuneate saltbush until March when all had fallen from the plants.

Utricles were weighed and cleaned by using a conventional hammer mill equipped with a 48 cm screen. Utricles were then separated into four size classes (Crofts 1977) within the size range of each species.

Utricle fill was determined by clipping and X-ray exposure of utricles from individual plants and from various locations on plants. Thickness of the utricle wall was measured on 50 cut seeds of each size for each species under a microscope equipped with an ocular micrometer.

Germination and seedling vigor were observed on seedlings planted along the front of glass-sided root observation chambers (Figure 4). Three replications of 50 utricles each of four size classes for each species were planted in moist sand in the chambers and allowed to grow for 14 days.

Field Survival of Container Grown Plants--

An additional 10 replications of the 3 shrub species grown from seeds or rooted cuttings in the various containers as described in study 1b were

[1/] Seeds of *Atriplex* species are enclosed in an outer shell termed a utricle which in some species may be an impediment to germination.

prepared in the greenhouse in the winter of 1975. After 4 months of growth in the greenhouse a total of 240 seedlings were outplanted on July 1, 1976 at 1-meter spacings in the field test site in the oil shale region. Percent seedlings survival of species in general and in relation to the influence of the propagation containers was observed during the first and second growing seasons.

Observe Moisture Patterns in Relation to Soil Surface Treatments

Soil Moisture Under Surfaces Treated with Stabilizing Materials--

Effective use of soil moisture is, with little doubt, the most critical factor in the establishment of plants in disturbed arid lands. To determine if favorable soil moisture conditions could be developed by treatment with soil surface stabilizing materials, soil moisture psychrometers as described by Van Havern and Brown (1972) were placed 15 cm under the surface of treatments applied in experiment 2a. Soil moisture readings were made one and two months after installation.

Soil Moisture in Relation to Root Growth of Outplanted Shrubs--

Root growth habits are important adaptations to soil texture and patterns of soil moisture penetration. Deep root growth, such as is found in *Sarcobatus vermiculatus*, may best be adapted to soils with high permeability and deep percolation while a plant like *Chrysothamnus linifolius* with shallow roots may best be adapted to soils with shallow percolation. Soil surface treatments such as weed control or application of stabilizing materials for water harvesting may alter the normal pattern of moisture distribution. A better understanding of soil moisture availability and plant use would assist in planning rehabilitation methods.

To determine how root growth of transplanted seedlings influences the pattern of moisture extraction where the surface has been cleared of competing vegetation, soil psychrometers were located at 30 cm depth in four of the ten replications of shrub transplants described in experiment 3b above. Moisture readings were made each 2 weeks from July 3 until October 20 and again in the spring from March to July. Because of severe but uneven rodent damage in the fall, each transplant was protected with a wire cage in the spring. Only the spring period of soil moisture readings are reported because of the uneven influence of rodent damage on plant growth the first few months after transplanting. Moisture readings obtained under dead plants served as control data.

SECTION 5

RESULTS AND DISCUSSION

Results from the four areas of research conducted provide useful data for improving the establishment of plants under arid conditions.

DEVELOP PROPAGATION AND PLANTING TECHNIQUES

Stem Cutting Propagation of Big Sagebrush

Root formation on cuttings was most effective when cuttings were taken just after buds emerged from dormancy in the early spring (Table 2). The percent of cuttings that rooted decreased progressively through the spring months until essentially no cuttings rooted at all. Rooting hormone treatments appeared to be essential to stimulate root formation. Cuttings did not root if they were not given a hormone treatment. However, the 2.0% IBA treatment was over 3 times more effective than the .3% level. Differences among plants to produce roots on cuttings were also noted.

The decrease in rooting response during the early spring months coincides with changes in other physiological processed (DePuitt and Caldwell 1973) and in available carbohydrate mobilization (Coyne and Cook 1970). Previous attempts to root sagebrush cuttings at less favorable times of the growing season can be better understood in light of these results. Guidelines for propagation of other native plants were developed following the results obtained with sagebrush (Institute for Land Rehabilitation 1979).

Container Volume as a Factor in Propagating Shrub Seedlings

Shrub seedling growth was favorably influenced by increasing container size. Larger containers were associated with taller plants, greater shoot biomass and greater root biomass (Tables 3, 4, 5). The smallest container restricted shoot and root biomass of each species during the entire 20-week growth period. In contrast, the two largest containers allowed growth to increase significantly every 2-4 weeks. Root biomass of spreading rabbitbrush, a plant expected to be inhibited by the constraints of a vertical container as contrasted with the other two species, did not appear to be considerably different. When roots were observed at each harvest period, root growth appeared spiraled in some of the containers. Spiraling was greatest in the milk carton. This was in contrast with results of Hiatt and Tinus (1974) who found spiral root growth to be generally greatest in cylindrical containers. Roots in the tubepak container showed no spiral growth.

TABLE 2. ROOTING PERFORMANCE OF BIG SAGEBRUSH (*ARTEMISIA TRIDENTATA* ssp. *WYOMINGENSIS*) CUTTINGS IN RESPONSE TO THREE CHEMICAL TREATMENT LEVELS AT FOUR SPRING SAMPLING DATES

Sampling date	Percentage rooting (avg. of five 30-cutting reps.)			Sampling date mean rooting percentage*
	Control 0.0% IBA	Low 0.3% IBA	High 2.0% IBA	
March 26	0.0	4.7	36.0	13.6 a
April 10	0.0	12.0	21.3	11.1 a
April 24	0.0	6.7	25.3	10.7 a
May 8	0.0	0.7	1.3	0.7 b
Mean rooting Percentage **	0.0	6.0 b	21.0 c	

* Means significantly different at 5 percent level. Values not followed by the same letter are significantly different at 5 percent level of Duncan's Test.

** Means significantly different at 1 percent level. Values not followed by the same letter are significantly different at 5 percent level of Duncan's Test.
There were no significant interactions at 5 percent level.

Fourwing saltbush and greasewood plants propagated from seedlings had greater root length, shoot biomass and root biomass than did plants propagated from rooted cuttings at the end of 20 weeks. The main differences in root morphology from propagation method was a multiple tap root appearance of stem cutting transplants as contrasted with the more common branched single tap root of seedling transplants.

Observations of root growth following transplanting indicated that root systems expanded rapidly and were not inhibited in any one direction by prior configuration of the propagation container. Deepest roots were those from plants grown in the deep container and the shallowest roots were from plants grown in the short, single-cell container. Fourwing saltbush transplants had a greater root system spread than did greasewood or spreading rabbitbrush.

TABLE 3. MEAN SHOOT LENGTH, SHOOT BIOMASS AND ROOT BIOMASS OF FOURWING SALTBUSH PLANTS HARVESTED AT 4-WEEK INTERVALS WHILE GROWING IN THE CONTAINERS. MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT THE 5 PERCENT LEVEL

Container Treatment	Weeks 4	8	12	16	20
	Shoot Length, cm				
Milk	10.0 abc	17.8 fg	34.5 hi	50.0 j	66.7 k
Deep	3.9 a	12.4 cdef	21.4 g	35.8 k	50.0 j
Tubepak	8.9 abc	11.5 bcdef	17.6 efg	16.7 defg	29.6 hi
Single Cell	4.6 a	6.4 abc	5.9 abc	8.2 abc	7.8 abc
	Shoot Biomass, g				
Milk	0.08 l	1.40 o	2.40 p	4.90 q	9.80 s
Deep	0.05 l	0.59 mn	1.10 no	2.30 p	5.60 r
Tubepak	0.08 l	0.78 mn	1.10 no	1.20 no	2.50 p
Single Cell	0.03 l	0.36 lm	0.21 lm	0.35 lm	0.41 lm
	Root Biomass, g				
Milk	0.02 t	0.18 tu	0.72 wx	1.80 z	4.30 b
Deep	0.01 t	0.11 tu	0.46 uvw	0.87 x	2.20 a
Tubepak	0.03 t	0.13 tu	0.34 tuv	0.67 vwx	1.30 y
Single Cell	0.01 t	0.04 t	0.13 tu	0.28 tu	0.34 tuv

Planting Techniques, Season and Kind of Planting Stock

Transplanting container grown plants resulted in significantly greater survival than planting bare root seedlings (Table 6). Both methods of transplanting are far superior to direct seeding which essentially failed. Seed germination was erratic and only weak seedlings developed from the seeds planted directly in the soil. By the end of 2 seasons after planting only an occasional plant can be found in the seeded rows.

In general, over 50 percent of the transplants survived although the rate of survival was considerably different for the various species. Best survival was recorded for greasewood at 68.1 percent, followed by big sagebrush at 66.6 percent, fourwing saltbush 61.8 percent, winterfat 59.7 percent, black sagebrush 58.3 percent, shadscale 50 percent, green's rabbitbrush 49.3 percent, cuneate saltbush 46.5 percent, and spreading rabbitbrush 29.2 percent.

Container-grown plants were 11.2 percent better in survival than bare root transplants. This might be expected in as much as the roots of the

TABLE 4. MEAN SHOOT LENGTH, SHOOT BIOMASS AND ROOT BIOMASS OF SPREADING RABBITBRUSH PLANTS HARVESTED AT 4-WEEK INTERVALS WHILE GROWING IN THE CONTAINERS. MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT THE FIVE PERCENT LEVEL

Container treatment	Weeks				
	4	8	12	16	20
	Shoot length cm				
Milk	13.8 bc	23.7 de	55.0 g	52.3 g	64.5 h
Deep	11.5 b	16.0 bc	30.3 f	30.2 ef	30.0 ef
Tubepak	14.0 bc	19.2 cd	26.8 ef	27.8 ef	24.5 def
Single Cell	4.3 a	12.3 bc	12.0 b	12.3 bc	13.7 bc
	Shoot biomass g				
Milk	0.08 i	0.46 ij	3.60 n	4.20 n	6.90 o
Deep	0.06 i	0.12 i	0.82 jk	1.60 lm	2.10 m
Tubepak	0.08 i	0.35 ij	0.89 jk	1.40 kl	1.90 lm
Single cell	0.01 i	0.08 i	0.15 i	0.28 ij	0.31 ij
	Root biomass g				
Milk	0.02 p	0.18 pq	1.90 s	3.50 t	4.00 t
Deep	0.02 p	0.04 p	0.57 qr	1.20 s	1.20 s
Tubepak	0.04 p	0.19 pqr	0.63 4	1.20 s	1.40 s
Single cell	0.01 p	0.06 p	0.18 pq	0.35 pqr	0.31 pqr

Planting Techniques, Season and Kind of Planting Stock

Transplanting container grown plants resulted in significantly greater survival than planting bare root seedlings (Table 6). Both methods of transplanting are far superior to direct seeding which essentially failed. Seed germination was erratic and only weak seedlings developed from the seeds planted directly in the soil. By the end of 2 seasons after planting only an occasional plant can be found in the seeded rows.

In general, over 50 percent of the transplants survived although the rate of survival was considerably different for the various species. Best survival was recorded for greasewood at 68.1 percent, followed by big sagebrush at 66.6 percent, fourwing saltbush 61.8 percent, winterfat 59.7 percent, black sagebrush 58.3 percent, shadscale 50 percent, green's rabbitbrush 49.3 percent, cuneate saltbush 46.5 percent, and spreading rabbitbrush 29.2 percent.

TABLE 5. MEAN SHOOT LENGTH, SHOOT BIOMASS AND ROOT BIOMASS OF GREASEWOOD PLANTS HARVESTED AT 4-WEEK INTERVALS WHILE GROWING IN THE CONTAINERS. MEANS WITH THE SAME LETTER ARE NOT SIGNIFICANTLY DIFFERENT AT THE 5 PERCENT LEVEL.

Container treatment	Weeks				
	4	8	12	16	20
	Shoot length cm				
Milk	4.3 abc	9.6 ef	21.7 h	37.8 j	44.9 k
Deep	5.2 abcd	5.9 abcde	14.5 q	22.2 h	29.3 i
Tubepak	3.5 ab	4.6 abc	7.7 bcde	13.7 fg	13.1 fg
Single cell	3.3 a	5.3 abcd	7.8 cde	13.5 fg	8.9 de
	Shoot biomass g				
Milk	0.03 l	0.67 opq	1.40 st	4.30 v	3.50 u
Deep	0.03 l	0.13 lm	0.39 lmno	1.10 rs	2.10 t
Tubepak	0.02 l	0.43 mno	0.52 nop	0.82 pqr	0.90 qr
Single cell	0.02 l	0.07 lm	0.15 lmn	0.27 lmn	0.20 lmn
	Root biomass g				
Milk	0.01 w	0.10 w	0.92 z	2.70 b	2.10 a
Deep	0.02 w	0.04 w	0.27 wy	0.61 yz	1.70 a
Tubepak	0.01 w	0.13 wy	0.44 wyz	0.61 yz	1.70 a
Single cell	0.06 wy	0.05 wy	0.14 wy	0.24 wy	0.21 wy

Container-grown plants were 11.2 percent better in survival than bare root transplants. This might be expected in as much as the roots of the container grown transplants are already in contact with a mass of soil and experience much less disturbance when planted than do bare root seedlings.

Fall planting gave 13 percent lower survival than spring planting. Some species such as fourwing saltbush had good survival when planted in fall or spring if container grown plants were used. Planting container grown stock generally increased plant survival by 10 to 15 percent for fall plantings.

Of the three sites used in this study, the amount of plant competition and site severity differed. One site had a 69.4 percent overall survival, while the others had 57.2 and 36.5 percent. There appeared to be a proportionately higher survival rate at the high competition sites for plants that were container grown as compared with bare root transplants. Damage by rodents and

TABLE 6. FIELD SURVIVAL OF NINE SHRUB SPECIES AFTER THREE YEARS IN THREE PLANTING SITES. PLANTS WERE PROPAGATED AS BARE ROOT OR CONTAINER GROWN PLANTING STOCK AND WERE PLANTED IN THE FALL OF 1975 AND SPRING OF 1976. SURVIVAL RECORDED IN SEPTEMBER, 1977 [1/]

Plant Species	Field Sites G-17	Sect. 6	G-3	Average Survival
Sarcobatus vermiculatus	64.6 cd	47.9 b	91.7 a	68.1
Atriplex canescens	64.6 cd	54.2 b	66.7 c	61.8
Atriplex confertifolia	60.4 cd	81.3 a	8.3 c	50.0
Atriplex cuneata	70.8 bc	68.8 a	0.0 c	46.5
Ceratoides lanata	62.5 cd	47.9 b	68.8 c	59.7
Chrysothamnus greenii	77.1 abc	0.0 d	70.8 bc	49.3
Artemisia nova	89.6 a	2.1 c	83.3 ab	58.3
Artemisia tridentata	85.4 ab	27.1 c	87.5 a	66.6
Chrysothamnus linifolius	50.0 d	0.0 d	37.5 c	29.2
Season of Planting				
Fall	60.6 a	30.6 a	52.7 a	47.8
Spring	78.2 b	42.6 b	61.6 b	60.8
Propagation Method				
BR	60.2 a	34.3 a	51.9 a	48.8 a
CO	78.7 b	38.9 a	62.5 b	60.0 b
Treatments				
Control	68.1 a	29.9 b	52.8 g	50.3
Irrigation	73.6 a	38.9 a	61.8 a	58.1
Irrigation + fertilizer	66.7 a	41.0 a	56.9 ab	54.8
Site	69.4 a	36.5 d	57.2 a	

[1/] Means are not significantly different if followed by the same letter.

other wildlife also contributed to reduced survival at all sites but these losses appeared to be greatest in the first year after planting.

Addition of water or water plus fertilizer at planting time did not prove to be statistically significant from the regular planting. The soil was moist at planting time which probably negated the need for irrigation. Under more xeric planting conditions in other studies we have found a beneficial effect by irrigation to settle the soil around the root/soil mass. The amount of fertilizer added did not aid in seedling growth or survival

but may have actually stimulated the growth of competing annual grasses according to field observations.

Plant survival in the xeric Henry Mountains coal field in south central Utah ranged from a low of 29.5 percent for fourwing saltbush to a high of 55.7 percent for cuneate saltbush (Table 7). On individual sites some species had excellent survival, reflecting ecological adaptation to inhospitable soil conditions. Two notable examples were the high survival of all species on the crushed saline sandstone outcrop and the high success rate of indian ricegrass on the loamy fine sandy soil. In contrast, two species had a complete failure on the silty clay soil.

TABLE 7. PERCENT SURVIVAL OF TRANSPLANTS ON SIX FIELD SITES IN THE HENRY MOUNTAINS, UTAH COAL FIELD. PLANTED APRIL, 1977. DATA ARE THE MEANS OF 24 PLANTS

Site	Fourwing Saltbush	Shadscale Saltbush	Cuneate Saltbush	Indian Ricegrass	Russian Wildrye	Site Averages
A. Cobbly sandy Loam, Pete Steele Bench	0	33	88	38	4	32.6
B. Crushed sandstone outcrop	67	63	69	29	67	59.0
C. Crushed gray shale outcrop	13	67	26	21	21	29.6
D. Crushed saline sandstone outcrop	84	100	100	88	100	94.4
E. Loamy fine sandy soil, Wildcat Mesa	0	25	44	92	100	52.2
F. Silty clay soil,	13	34	7	0	8	12.4
Species Averages	29.5	53.7	55.7	44.7	47.8	

TABLE 8. EVALUATION OF SURFACE STABILIZING MATERIALS APPLIED ON JULY 1 FOR STRENGTH AND BINDING PROPERTIES USING A FIVE-POINT RATING SCALE [1/]

(values are the mean of four replications)

	Material/Rate	Mean Rating July 15	Mean Rating Sept 3	Runoff Test [2/] Aug 22
1	Check	1	1	2/10
2	Plastic	5	5	10/10
3	Coherex/Low	1	1	9/10
4	Coherex/Med	1.5	1	8/10
5	Coherex/High	1.5	1	9/10
6	Soil Seal/Low	2.5	2	9/10
7	Soil Seal/Med	2.7	2	6/10
8	Soil Seal/High	4.0	3	7/10
9	Aerospray 70/Low	4.0	4	4/10
10	Aerospray 70/Med	4.1	4	3/10
11	Aerospray 70/High	4.0	4	5/10
12	Trastan/Low	1.5	1	1/10
13	Trastan/Med	2.0	1	1/20
14	Trastan/High	1.2	1	2/10
15	Paracol 1461/Low	1.1	1	6/10
16	Paracol 1461/Med	1.0	1	9/10
17	Paracol 1461/High	1.2	1	9/10
18	TerraTack II/Low	1.8	2	3/10
19	TerraTack II/Med	1.0	2	1/10
20	TerraTack II/High	1.0	2	1/10

[1/] 1 = no resistance to pressure, water soaks in, no particle adhesion
2 = slight pressure resistance, water slowly soaks, slight particle adhesion
3 = moderately firm - resistant, water is repelled, many particles loose
4 = firm, pressure resistance, water beads and runs and few particles loose
5 = hard, resists pressure, water runs off, all particles bonded together

[2/] Portions of one liter or water running into furrow at bottom of plot Slope 1:10.

Without the application of irrigation water all of the plants would have perished because of the extreme aridity and lack of the occasional summer storm during the study period. Results of the study show that with container grown plants and some irrigation water during the first few months of establishment, plant survival approaching 50 percent can be realized even when soil is dry at planting and no rainfall subsequently occurs. Results also point out the need for careful selection of species adapted to environmental extremes such as very fine or very coarse soil texture and salinity.

MATERIALS FOR SOIL SURFACE STABILIZATION

Field Evaluation of Soil Surface Stabiling Agents

Only one of the materials tested under conditions of the field study site proved to be effective (Table 8). Polyvinyl acetate received an initial rating of four on a five-point scale two weeks after application. This favorable rating was maintained for an additional 7 weeks as noted on September 3. Other materials generally lost their effectiveness for surface stabilization, according to the criteria of evaluation, soon after application, possibly due to the high temperatures and summer rainshowers which occurred on the test site. We cannot rule out the possibility that the rates or methods of application were inappropriate for the other materials. Thus, under other circumstances other materials or formulations might be effective.

A visual runoff test 7 weeks after application of surface stabilizing materials showed that some materials were more effective in shedding water than their surface strength rating suggested. Those materials which promoted the highest water runoff included the asphalt emulsion, the co-polymer of methacrylates and acrilites, the polyvinyl acetate, and the lignosulfonate resins and wax. Some of the water harvesting character of these materials appeared to be as a result of a water repellency imparted to the soil surface rather than reduced permeability.

A subsequent evaluation of the surface treated plots one year later indicated that all had lost any surface film character that had existed earlier. Small broken pieces of the polyvinyl acetate still existed on the surface but no water harvesting effectiveness remained and only a minimal surface binding action was considered possible.

Results of this test suggest that a short term advantage in soil or spoil stabilization would be obtained by application of a surface stabilizing agent - possibly for 1 year. During that time, water harvesting from short slopes may be possible to aid in plant establishment.

Water Harvesting Basins Treated with Soil Surface Stabilizing Materials

The amount of water harvested in basins of two different sizes was not proportional to basin size -- primarily because of basin geometry. The bottom of the 1.5 m (5 ft) diameter basins did not slope into the can in the bottom but tended to flatten out and as a result, some of the runoff water from the sides percolated through the surface sealant before getting to the center of

of the basin. This faulty design accounts for the erratic results obtained in the amount of accumulated runoff measured on September 23, 1976. For this reason, data from the large basins are not included in this report.

The .75 cm (2.5 ft) diameter basins appeared to be correctly shaped for optimum water harvesting and directed any runoff into the can in the center of the basin. One week following a .42 cm (.17 inch) rain, the collection cans in the bottom of the basins treated with split application of the surface stabilizing material (treatments 3 and 5) more than doubled the amount of runoff from the control (treatment 1) (Table 9). Low rates of surface stabilizing material were no better than the untreated control.

TABLE 9. CUBIC CENTIMETERS OF WATER COLLECTED IN CANS IN THE BOTTOM OF .75 M DIAMETER, 10 CM DEEP BASINS TREATED WITH A POLYVINYL ACETATE STABILIZING COMPOUND. MEASUREMENTS WERE MADE ON SEPTEMBER 23, 1976, ONE WEEK AFTER A .42 CM RAINFALL.

	Treatment [1]				
Replication	1	2	3	4	5
I	1150	0	1340	420	2320
II	120	1610	2060	50	2600
III	1510	1580	1930	150	1320
IV	140	140	2420	2300	2320
Total	2920	3330	7750	2920	8560
Average [2]	730 c	832 bc	1937 ab	730 c	2140 a

[1] Treatments

1 check
2 1900 liters of concentrate per ha.
3 3800 liters of concentrate per ha.
4 950 l/ha + 950 l/ha reapplied.
5 1900 l/ha + 1900 l/ha reapplied.

[2] Means not significantly different (PS .05) if have same letter in that signif. column.

Following an application of .5 cm (.20 inch) of simulated rainfall on September 23, runoff harvested into the cans in the bottom of the .75 cm diameter basins was over twice as great for basins treated with a split application of material as for basins treated once (Table 10). Approximately the

same amount of water was harvested from the non treated basins as from the ones given the low treatment rate.

TABLE 10. CUBIC CENTIMETERS OF WATER HARVESTED FROM A SIMULATED RAINFALL OF .5 CM (.20 INCH) APPLIED WITH A SPRINKLER CAN TO BASINS .75 M IN DIAMETER AND 10 CM DEEP

	Treatment 1/				
Replication	1	2	3	4	5
I	245	530	1560	1230	1260
II	430	720	1100	250	1010
III	200	750	1470	220	1150
IV	800	70	1290	750	1580
Total	1675	2070	5420	2450	5000
Average 2/	419	518	1355	612	1250

1/ Treatments

1 check.
2 1900 liters of concentrate per ha.
3 3800 liters of concentrate per ha.
4 950 l/ha + 950 l/ha reapplied.
5 1900 l/ha + 1900 l/ha reapplied.

2/ Means not signif. different (PS .05) if have same letter in that signif. column.

Most important is the evidence of water harvested in basins whether surface treated or not. Compared with circumstances of no concentration, the basins show a high potential for concentrating precipitation received at the soil surface into control points where it could aid in plant establishment in arid locations.

After the collecting cans were removed and containergrown fourwing saltbush transplants were planted in the basins, a dense stand of cheatgrass (*Bromus tectorum*) developed in the vicinity of the transplants. In the previous year the surface treatment prevented the growth of this weed. In spite of this competition, 100 percent survival of all transplants occurred during the following season. Stem growth of transplants in basins was approximately twice the length of stems on plants not in basins.

These results suggest the feasibility of creating basins and treating the side slopes with a soil stabilizing agent to harvest water and to control early competition from weeds. The favorable micro site thus could increase the survival of transplanted shrub seedlings in an arid environment.

ECOLOGY OF SELECTED NATIVE PLANTS

Germination and Seedling Vigor of Four *Atriplex* Species

Utricle size did not differ with the position on the indeterminately flowering stem. Thus, maturity or date of ripening also did not appear to be a factor in seed size because the utricles mature progressively from the bottom to the top of stems. These results indicate there would be no advantage to harvesting utricles from only a given portion of the stem or emphasizing a certain time of collection in so far as seed size is concerned.

Utricle fill appeared to be related to phenological development (Table 11). At a given date utricles of *Atriplex confertifolia*, *A. canescens* and *A. cuneata* differed in their fill depending on their spikelet location. Utricles collected from *A. confertifolia* on 17 October were still relatively immature. Yet, fill was highest in this species on the lowest portion of the utricle-bearing stem and progressed upwards. Two months later maximum fill was associated with the latest ripening utricles found near the tip of the inflorescence. Thus whenever utricles are collected, a cutting test should be made to verify whether utricles closest to the tips of the spikelets are at full maturity and fill.

TABLE 11. PERCENTAGE OF FILLED UTRICLES AS RELATED TO POSITION OF THE UTRICLE ON THE STEM 1/

Species	Collection Date	Percent Seed Fill		
		Top	Middle	Bottom
Atriplex confertifolia	17 October *	59.5 b	62.5 ab	70.0 a
	12 December *	37.0 a	23.0 b	17.5 b
Atriplex cuneata	5 September	25.5	25.9	30.0
Atriplex canescens	7 October	62.5 a	57.5	40.0 b
Atriplex gardneri	17 October	53.0	51.0	59.0

1/ Means in each row followed by the same letter are not sifniciantly different (.05 level).

* Seeds collected from same plant.

Sizing of utricles from bulk collections revealed a relationship of utricle size to fruit fill (Figure 5). In three of the four species tested, larger utricles also had a higher percent fill. This relationship did not hold true for *A. cuneata*. The highest percent fill of utricles collected during the fall and winter from individual plants of *A. confertifolia* and *A. canescens* was associated with a mid-fall collection date. Thus, for optimum percent utricle fill, mature seeds should be collected and very small seeds should be separated out.

Thickness of the utricle wall was found to be associated with utricle size (Figure 6). Wall thickness of less than .30 mm was measured in small utricles. Large utricles had walls greater than .40 mm thick. *A. confertifolia*, known for its hard utricles, had walls as thick was .60 mm, whereas *A. canescens* had walls just over .40 mm in its largest utricles. Because of the variability in wall thickness for each size class of a given *Atriplex* species, utricles should be separated into size classes prior to scarification. Thus, the mechanical effects of the scarification would have equal effect on a uniform batch of utricles and not proportionately do higher damage to the smaller utricles or inadequately scarify the larger ones. Seedling vigor was characterized in terms of germination rate and percentage, root growth, and mortality.

Germination percentages and rates varied in relation to size classes of three of the four species tested (Figure 7). Significantly lower germination was associated with the largest utricle size of *A. cuneata* and *A. gardneri*. Conversely, significantly lower germination was associated with the intermediate size class of *A. confertifolia*. While not conclusive, a general trend for lower and slower germination percentage appeared to be associated with medium to large utricles. This trend has been noted by others (Nord and Whitacre 1957) but is contrary to general seed germination response in which large seeds are more active and produce more vigorous seedlings than small seeds (McKell 1972).

Longest roots were associated with smallest utricles with the exception of *A. confertifolia* which showed no relation between utricle size and root length. Roots became progressively shorter as utricle size class increased. The longest roots were observed on *A. canescens* seedlings and the shortest on *A. confertifolia*. Some root abberations were noted in the observation chambers but these were associated with utricles that showed an abnormal germination pattern such as radicle or top growth only.

Mortality of *A. cuneata* seedlings was significantly greater in those from large than from small utricles. The same trend was evident, although not significantly so, with the other *Atriplex* species. The results of this study suggest that as long as utricles are filled, small to medium utricles should be selected over large ones for planting. Such a recommendation is consistent with other findings regarding germination and utricle wall thickness.

Field Survival of Container Grown Plants

Field survival results give further insights to the effect of container size and shape on species of different tolerances. The highest survival rate of the three species studied was shown by greasewood at 72 percent, fourwing

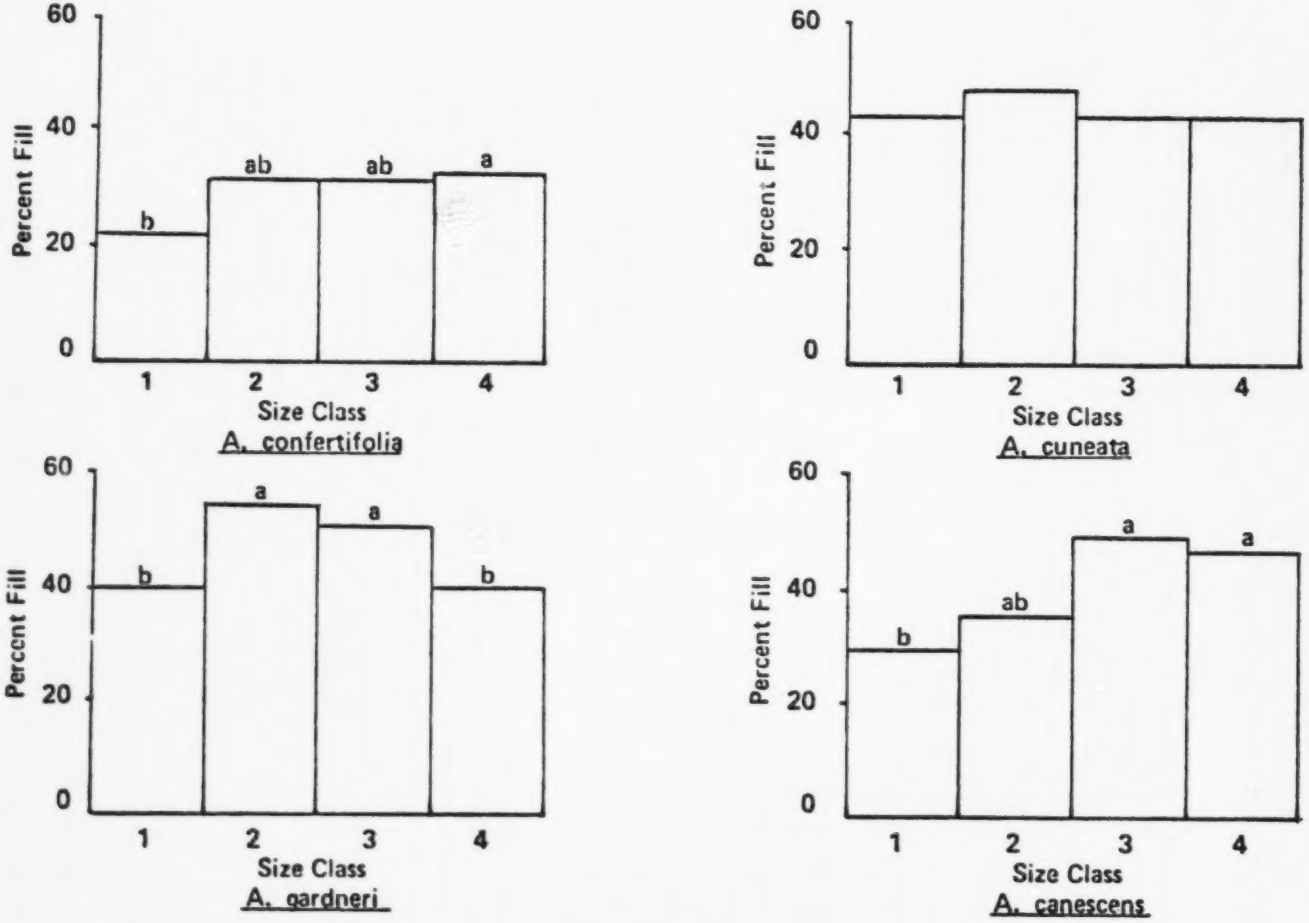

FIGURE 5. THE EFFECTS OF UTRICLE SIZING ON THE PRESENT FRUIT FILL FOR FOUR SPECIES OF HAMMERMILLED SALTBUSH FRUITS. COLUMNS NOT HAVING THE SAME LETTER ARE SIGNIFICANTLY DIFFERENT AT THE 0.05 LEVEL USING DUNCAN'S MULTIPLE RULE RANGE TEST. FOR EACH SPECIES, SIZE 1 INCLUDED THE SMALLEST UTRICLES AND SIZE CLASS 4 THE LARGEST.

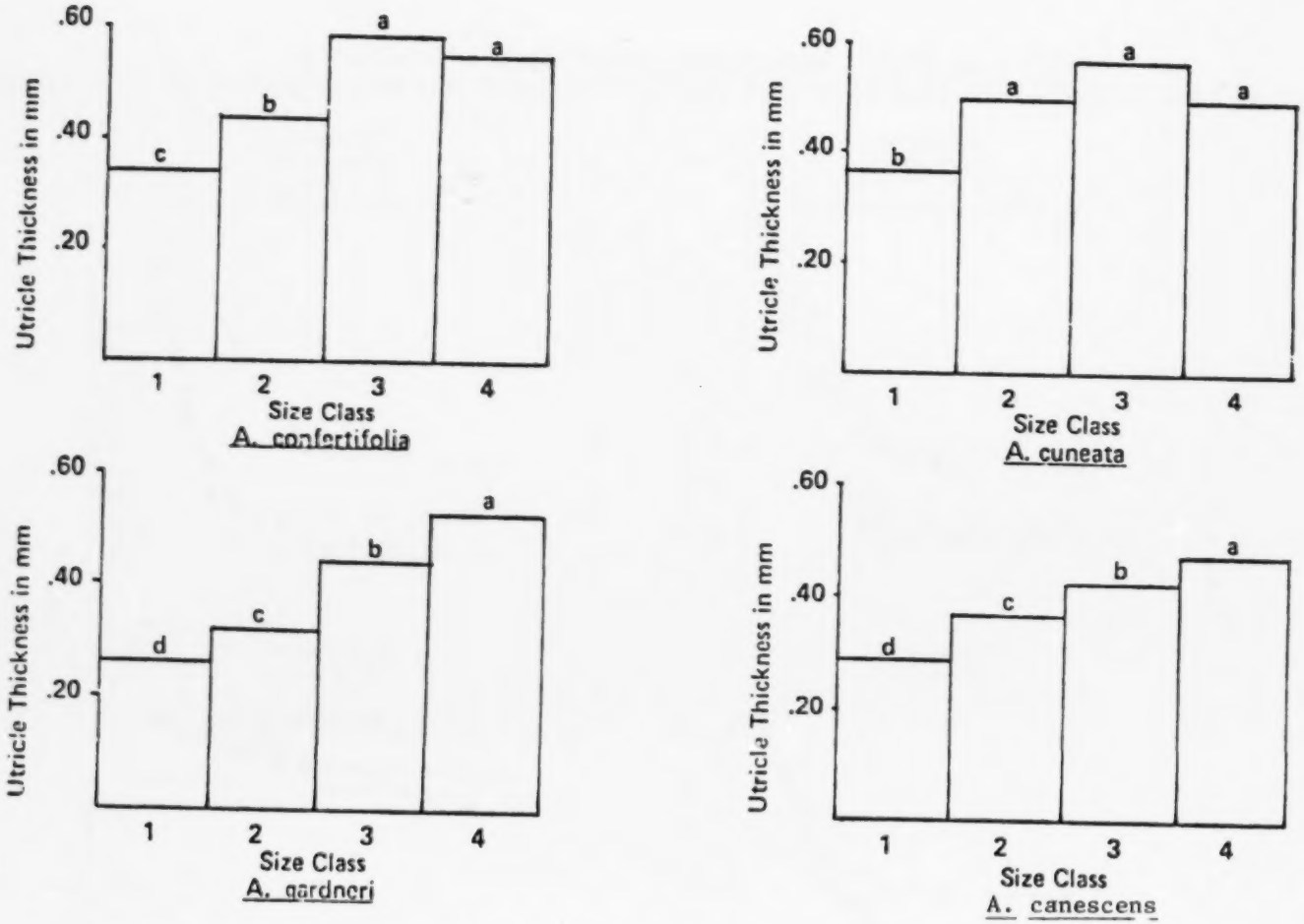

FIGURE 6. THE INFLUENCE OF UTRICLE SIZE AND UTRICLE WALL THICKNESS OF FOUR SPECIES OF HAMMERMILLED SALTBUSH FRUITS. COLUMNS NOT HAVING THE SAME LETTER ARE SIGNIFICANTLY DIFFERENT AT THE 0.01 LEVEL USING DUNCAN'S MULTIPLE RULE RANGE TEST. FOR EACH SPECIES SIZE CLASS 1 INCLUDED THE SMALLEST UTRICLES RANGING TO THE LARGEST IN SIZE CLASS 4.

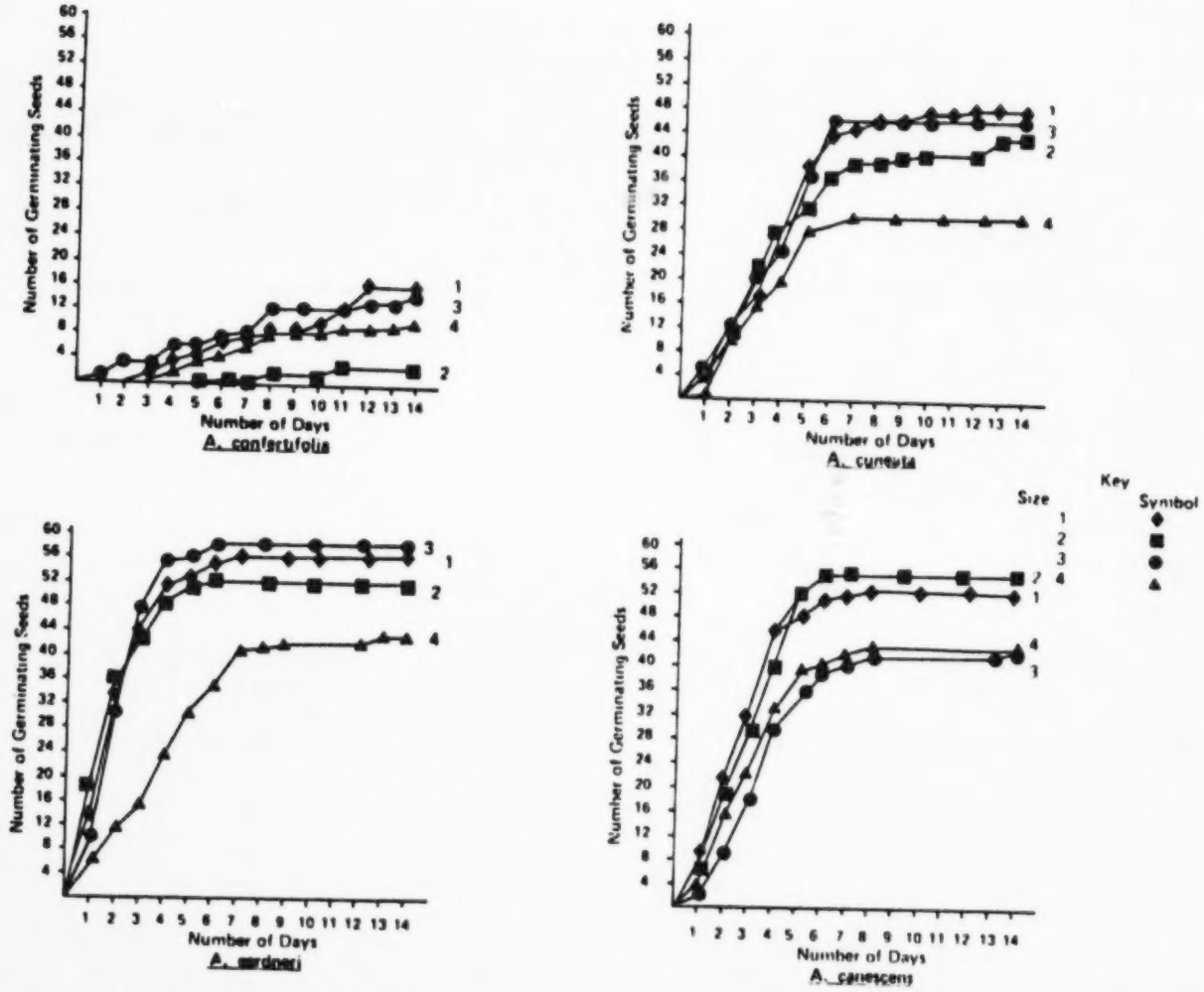

FIGURE 7. DAILY GERMINATION PERCENTAGES OF EXCISED SEED BY UTRICLE SIZE CLASS OF FOUR SPECIES OF *ATRIPLEX*. SIZE CLASSES RANGED FROM 1 SMALL TO 4 LARGE.

saltbush was intermediate at 66 percent, and the lowest was spreading rabbitbrush at 53.8 percent. These survival rates are extremely favorable in view of the arid environment of the research site.

At the end of the growing season following planting, a larger number of seedlings grown in the milk cartons survived than those grown in the single cell (Table 12). By the beginning of the second growing season, survival of plants in the smaller containers decreased about 10 percent. Plants grown in the milk cartons continued to show a very favorable 88 percent survival.

Seedlings appeared to be better able to withstand stress than rooted cuttings as seen by a 10 percent difference in their field survival after 12 months (Table 12).

TABLE 12. MEAN SEEDLING SURVIVAL AT TWO DATES AFTER OUTPLANTING ON JULY 1 FOR THREE SHRUB SPECIES GROWN IN FOUR CONTAINERS WITH TWO PROPAGATION METHODS. MEANS WITH THE SAME LETTER FOR EACH DATE ARE NOT SIGNIFICANTLY DIFFERENT.

Container	10/20/76	7/5/77
Milk	88.3 a[1]	88.3 a[1]
Deep	76.6 ab	65.0 b
Tubepak	73.3 ab	63.3 b
Single cell	65.0 b	40.0 c
Species		
SAVE	87.5 m[2]	72.5 m[1]
ATCA	75.0 m	66.3 n
CHLI	65.0 n	53.8 o
Propagation		
Seedlings	78.0 x	69.0 x[3]
Cuttings	73.0 x	59.0 y

[1] Significance at the 1 percent level
[2] Significance at the 5 percent level
[3] Significance at the 10 percent level

SOIL MOISTURE PATTERNS IN RELATION TO SOIL SURFACE TREATMENTS

Soil Moisture Under Surfaces Treated with Stabilizing Materials.

A fallow effect was created by the clearing of vegetation around and on the plots treated with various soil stabilizing materials. Soil moisture

at 15 cm depth appeared to be equal for all plots 3 weeks after application and early in the following spring. Growth of shrub transplants in the furrow at the bottom of each treated plot reflected the general favorability of soil moisture on all plots. From an average initial growth of 15 cm, plants grew to an average of 45 cm from July 9 to November 13.

Soil Moisture Use by Variously Propagated Shrub Transplants in an Area Cleared of Competing Vegetation.

The main differences in soil moisture use among transplanted shrub occurred in June and early July of the second year after outplanting (Figure 8). For this reason the first year trends are not shown. In the late winter and early spring months all species, regardless of propagation method or type of container used in greenhouse preparation showed similar moisture use. Early spring rain increased the soil moisture considerably from the low levels that prevailed during the winter and thus delayed the start of rapid moisture depletion until May. On June 9 plants grown in tubepak containers and milk cartons depleted the soil moisture to a greater degree than those grown in the deep container or the small single cell. Later in the season all plants depleted soil moisture to the same degree but significantly more than the control which was the average of plots in which plants had died.

Species differences were evident by mid summer. On July 9, *Sarcobatus vermiculatus* and *Atriplex canescens* had depleted soil moisture to approximately -18 bars while *Chrysothamnus viscidiflorus* had only depleted moisture to -12 bars. Interpreted in terms of plant performance, a more negative soil moisture reading indicates a more effective root system and possibly a higher survival rate (see Table 12).

In the later part of June and early July seedlings depleted soil moisture to a greater degree than cuttings. This result reflects the generally better survival percentage and growth of seedlings over cuttings.

The moderate decline in soil moisture under the dead plants (used as a control or reference) indicates how a general reduction in the number of competing plants can help to conserve moisture in the soil. Even so, there is a gradual loss of moisture due to capillary rise and unsaturated moisture flow to the surface.

Results of this study show a close relationship between moisture use and plant growth and survival. Plant species with effective root systems to extract moisture from a larger volume and greater depth of soil also show higher survival numbers. Containers which foster a larger root system also appear to allow for greater survival.

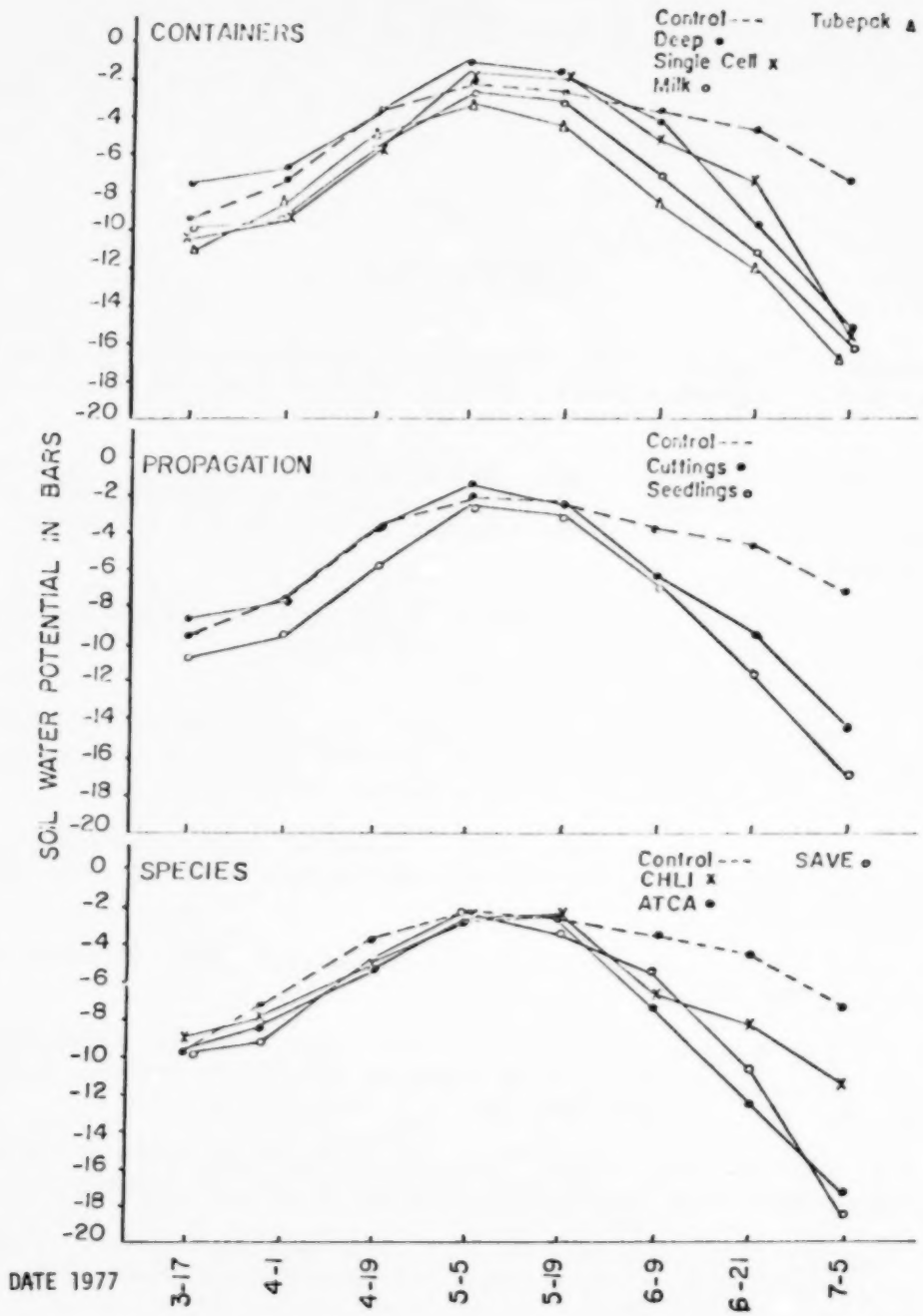

FIGURE 8. SOIL MOISTURE USE IN THE FIRST PART OF THE SECOND SEASON OF GROWTH FOR THREE SPECIES OF TRANSPLANTED SHRUBS PROPAGATED AS SEEDLINGS OR CUTTINGS AND GROWN 20 WEEKS IN VARIOUS CONTAINER TYPES PRIOR TO OUTPLANTING.

SECTION 6

LITERATURE CITED

Alvarez-Cordero, Eduardo. 1977. Stem cutting propagation of big sagebrush (*Artemisia tridentata* Nutt). M.S. Thesis Utah State University, Logan, Ut. 122 p.

Baker, E. and W.J. Duffield. 1973. Annual revegetation report. in Bloch, M.B. and P.D. Kilburn (eds). Processed Shale Revegetation Studies 1965-1973 Colony Development Operation, Atlantic Richfield Co. Denver, Colorado.

Barker, Jerry R. 1978. The influence of containers and propagation methods on shrub growth before and after field planting. M.S. Thesis. Utah State University, Logan, Ut. 90 pp.

Bleak, A.T., M.C. Frischknecht, A.P. Plummer, and R.E. Eckert, Jr. 1965. Problems in artificial and natural revegetation of the arid shadscale zone of Utah and Nevada. J. Range Manage. 18:59-65.

Block, M.B. and P.J. Kilburn (eds) 1973. Processed shale revegetation studies, 1965-1973. Denver: Colony development operation. Atlantic Richfield Co.

Collins, C.M. 1901. Seeds of commercial saltbushes. USDA, Division of Botany. Bulletin 27: 28 pp.

Cook, C.W., R.M. Hyde, and P.J. Simms. 1974. Guidelines for revegetation and stabilization of surface-mined lands in the Western States. Range Sci. Ser. No. 16. Colorado State Univ. Ft. Collins, Co.

Coyne, P.I. and C.W. Cook. 1970. Seasonal carbohydrate research cycles in eight desert range species. J. of Range Manage. 23:438-444.

Crofts, Kent A. 1977. The importance of utricle-related factors in germination and seedling vigor of four species of perennial *Atriplex*. M.S. Thesis. Utah State University, Logan, Ut. 91 p.

DePuit, E.J. and M.M. Caldwell. 1973. Seasonal pattern of net photosynthesis of *Artemisia tridentata*. Amer. J. Bot. 60:426-435.

Federal Register. 1973. 38:230 Part III. Washington, D.C. U.S. Government Printing Office.

Hiatt, H.A., and R.W. Tinus. 1974. Container shape controls root system configuration of Ponderosa Pine. P. 194-196 in R.W. Tinus, W.I. Stein and W.E. Balmer, eds. Proc. of the North American containerized forest tree seedling symposium. Great Plains Agric. Counc. Publ. No. 68.

Institute for Land Rehabilitation. 1979. Propagation and establishment of native plants in disturbed arid lands. Bulletin. Utah State Univ. Agric. Exp. Stn. (in Press).

McKell, C.M. 1972. Seedling vigor and seedling establishment pp. 76-87. in U.B. Youngher and C.M. McKell (eds). The Biology and Utilization of Grasses. Academic Press, New York and London 426 pp.

McKell, C.M., J.P. Blaisdell and J.R. Goodin (eds) 1972 Wildland Shrubs Their Biology and Utilization. USDA, Forest Service Gen. Tech. Report. INT-1 494 pp.

Nord, E.E. and J.C. Whitacre 1957. Germination of fourwing saltbush seed improved by scarification and grading. USDA Forest Service, California Forest and Range Exp. Stn. Res. Note 125. 5 p.

Plummer, A.P., D.R. Christensen and S.B. Monsen. 1968. Restoring big game ranges in Utah. Utah Department of Natural Resources, Div. of Fish and Game. Publication 68-3. 85 pp.

Valentine, John. 1971. Range Development and Improvements. Brigham Young Univ. Press, Provo, Utah. 516 pp.

Van Havern B.P. and R.W. Brown. 1972. The properties and behavior of water in the soil-plant-atmosphere continuum. P. 1-28 in R.W. Brown and B.P. Van Havern, eds. Proc. of Psychrometry in water relations research. Utah Agric. Exp. Stn. Utah State University. Logan, Ut.